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REVIEW OF WORK DONE BY SOUTHWEST RESEARCH INSTITUTE ON THE STORAGE OF AUDIO TRANSCRIPTION MATERIALS

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INTRODUCTION

The approach to this problem has been:

1. To catalogue the manifestations of shelf aging of phonograph discs and magnetic tapes which decrease their value as audio transcriptions.
2. To catalogue the basic mechanisms of degradation that result in the aforementioned manifestations.
3. To seek means, compatible with library operation, of eliminating or inhibiting the action of these mechanisms of degradation.

The scope of this study has been limited to the already mentioned objectives, and does not include such studies as those of playback degradation and development of longer lived audio transcription materials. In addition, the realities of library operation precluded study of technically sound, but nevertheless impractical, techniques such as low temperature storage in an inert atmosphere. Actual program work has been a compromise between theoretical research into the nature of audio transcription materials and an investigation of the utility of increasing their shelf life by practical measures. This study has been made by a combination of literature search, theoretical analysis, and laboratory work. The findings have, in one respect, been prosaic in that such problem solutions as novel anti-aging coatings have not been developed; but the findings do clearly demonstrate that proper storage techniques and environments will increase considerably the storage life of audio transcriptions.

The northeast book stack area of the Library of Congress was

chosen as a typical library environment for this study. Remembering that audio transcription materials are organic materials, the preliminary evaluation of this library environment indicated that three primary factors of deterioration should be investigated--heat, moisture, and dust. Deteriorative agents to be investigated were biological, chemical, and physical. One would expect the biological agent to be fungi and that such deterioration would be evidenced by surface marring. One would expect the chemical agents to be oxygen, atmospheric contaminants, water, incompatible ingredients of packaging materials, and internal chemical changes and that such deterioration would be evidenced by changes in the physical properties of the material itself. One would expect the physical agents to be heat, water, dust, and stress, and that such deterioration would be evidenced by surface marring and dimensional changes.

An obvious approach to the study of increasing the longevity of audio transcriptions by storage technique and environmental control was therefore taken, consisting of:

1. Sampling of the stacks and inspection of degraded records.
2. Exposing new records to the agents of deterioration in accelerating environments.[*]
3. Investigating more completely the agents which caused the most deterioration in the tests or which duplicated the deterioration found in sampling.

[*] The rate of deterioration caused by an agent (such as fungi or oxidation) is accelerated by changes in an environmental factor (such as heat or moisture).

4. Investigating means of eliminating or inhibiting deterioration of the records by operating on the environmental factors or agents or by changes in storage techniques.

The results of this approach indicate that improving the existing storage environment and use of appropriate storage techniques will materially increase the shelf life of audio transcriptions stored therein. Since each of the materials poses a different set of problems, the recommendations for such improvement of environmental control are presented in the discussion of the individual audio transcription media which follows.

DISCS

A proper classification of discs seems to be one based on their type of construction, i.e.:

1. Laminate, consisting of a structural core with a thermoplastic coating. The only currently made laminate discs are the "acetates" which have an aluminum core and a nitrocellulose lacquer coating. Acetates are used for instantaneous recording or as masters in the production of pressings. Glass was used as a core material during World War II. Many of the early pressings were laminate discs using a cardboard, phenolic plastic, or other rigid material for the core and a shellac coating into which the grooves were pressed. Collections contain examples of all of these types.

2. Composition, consisting of an aggregate with a thermoplastic binder. Most of the currently made 78 RPM, normal groove, records are of this type, using calcium carbonate (crushed limestone) and carbon black as the aggregate and the copolymer of vinyl chloride - vinyl acetate as the binder. It is common to replace some of the copolymer with such materials as Vinsol or Valite (cellulosic byproduct resins). The greatest number of shellac discs were composition type. The discouraging feature of shellac discs, from a storage viewpoint, is the common practice of using such materials as sawdust and clay for the aggregate and the use of a wide

variety of waxes and resins in the binder. Often a "shellac" disc contains no shellac at all. The usual composition formulation uses 30% or less by weight of binder. In 1949, 60% of the discs pressed were of the composition type. This formulation is becoming less common because it is not satisfactory for LP, low noise pressings.

3. Plastic, consisting of a plastic with less than 25% by weight of filler. This type of disc is only about 20 years old but is the most common type of pressing today. The plastic material is usually the copolymer of vinyl chloride - vinyl acetate and it is not unusual to extend it as much as 25% with such materials as Vinsol or Valite although the finest records are unfilled and unextended. Polystyrene has been used for the past five or six years, instead of the copolymer, by some companies, because it can be injection molded. (Decca is presently making LP's of polystyrene.)

The discs studied in this program are:

1. Laminate - instantaneous acetates.
2. Composition - shellacs.
3. Plastic - vinylites.

The basis of this selection was not only that of choosing the more common types of disc for study, but also recognition of the fact that a librarian cannot identify and care for discs in more detailed categories than these.

THE ACETATE DISC

Most audio transcription media have been in use for a shorter time than the potential storage life of the materials from which they are made. As a result, there is little knowledge available from experience which can be used as a guide for determining optimum storage techniques and environments for these media. However, this is not quite true for the acetate disc, as there are many examples of acetates which have failed under good library storage conditions. This indicates that the potential storage life of these discs is not much longer than the length of time this type of disc has been in use, and also that especial care must be taken of these discs.

Why? [illegible]

Warping and non-uniform deformation of these records is not a problem because of the strength of the core. Maintenance of vertical storage attitude, constant temperature and humidity environment, prevention of surface imprint from gravity loads, and prevention of surface marring from the sliding of material across the disc surface should provide adequate protection against the physical agents of deterioration.

The short potential life of acetate discs is due to their chemical formulation. Acetate disc coatings are made of nitrocellulose plasticized with castor oil, and both of these materials are extremely susceptible to both chemical and fungal deterioration. Most of the failures observed in this study were due to loss of plasticizer and this will be discussed first.

Castor oil is a non-solvent plasticizer (sometimes classified as a softener) which is dispersed in the nitrocellulose in discrete droplets.

The loss of this plasticizer causes shrinking and embrittlement of the coating, even if no chemical change has occurred in the nitrocellulose. Under optimum storage conditions, this plasticizer is lost by the very slow process of oxidation to form volatile compounds which diffuse from the coating. This rate of plasticizer loss can be accelerated tremendously by heat, moisture, wicking or fungal consumption. Under the influence of heat, the castor oil droplets often coalesce into large aggregates as a result of internal diffusion and ultimately "sweat out" or exude. High humidity increases the rate of this diffusion. Plasticizer loss was the only source of degradation which affected fidelity noted after subjecting these records to the accelerated aging tests.

The accelerated aging tests were performed as indicated in the following schedule:

1. Constant Temperature and Humidity Tests

Discs Tested*	Temp.	Time	Humidity R.H.	Air	Remarks
2-AX and 2-AY	120°F	1 mo.	$>90\%$	Circulating	Noise + 4 db**
2-BX and 2-BY	135°F	1 mo.	$>90\%$	Circulating	No chg. in freq. or distortion; some coating failure
2-AX and 2-AY	150°F	1 mo.	$>90\%$	Circulating	Noise + 7 db
4-BX and 4-BY	150°F	1 wk.	$>90\%$	Stagnant	Coating failure
2-AX and 2-AY	120°F	1 mo.	$>90\%$	Stagnant	Coating failure
2-BX and 2-BY	150°F	1 mo.	$<10\%$	Circulating	No chg. in freq. or distortion
2-AX and 2-AY	150°F	1 mo.	$<10\%$	Stagnant	Noise + 7 db after removing oil

2. Constant Temperature with Humidity Changed Each 24 Hours - Air Circulating

Discs Tested*	Temp.	Time	High Humidity	Low Humidity	Remarks
2-AX and 2-AY	120°F	1 mo.	> 90%	< 10%	Noise + 4 db
2-AX and 2-AY	150°F	1 mo.	> 90%	< 10%	Noise + 7 db
2-BX and 2-BY	150°F	1 mo.	> 90%	< 10%	No chg. in freq. or distortion

3. Constant Humidity with Temperature Changed Each 24 Hours - Air Circulating

Discs Tested*	High Temp.	Low Temp.	Time	Humidity	Remarks
2-AX and 2-AY	120°F	-40°F	1 mo.	< 10%	No change
2-BX and 2-BY	120°F	-40°F	1 mo.	< 10%	No change

4. U.V. Exposure Only; ∝ 70°F and 50% R.H.

2-BX for 1 month, no change in frequency, distortion or noise.

* A - unmodulated groove disc

B - test frequency disc

X - new disc

Y - new disc exposed to 24 hours Ultraviolet light before test

** Noise level is in relation to first play noise of new disc.

These accelerated aging tests were made for the purpose of determining significant mechanisms of degradation and the manifestations of degradation which affect the playback fidelity of the discs. No attempt was made to determine degradation rates of the discs in typical storage environments because (1) of the experience data available on these discs

which enable rational predictions of longevity to be made and (2) it was estimated that acquisition of the empirical data required to determine reaction and diffusion rates would be too expensive and time consuming for this program. It should be noted, however, that, qualitatively, manifestations of accelerated aging are the same as the manifestations of ordinary shelf aging. As indicated by Latham[1] and private communications with others, acetate discs seem to retain their frequency response and distortion characteristics until failure of the coating while there is an increase in noise level occasioned by loss of plasticizer. Under uncontrolled storage conditions, coating failure may occur in ten to twelve years, while under good storage conditions an acetate disc may exhibit only an increase in noise level of the order of 6 db in that time and the coating should have a dependable storage life of the order of 25 years. What data substantiates this figure?

During exposure and cycling, selected grooves were periodically replayed and, at the end of the exposure or cycling, previously unplayed grooves were played. Measurements of noise were made on the unmodulated groove discs and measurements of frequency response and distortion were made on the frequency test discs. It was found that there was no measurable change in frequency response or distortion until catastrophic failure of the coating. In the replayed grooves, the noise fell to about one-third of the first play intensity and remained at that low intensity during the remainder of the test. In the unplayed grooves, after 30 days exposure or 20 cycles, it was found that the noise level had risen to from 4 to 7 db relative noise level, based on the first play of the other grooves. This was associated with a loss in weight

[1] Latham, Wm. S., "Tape Life", U. S. Navy Underwater Sound Laboratory, IRE Convention Record, 1955 National Convention, Audio III Seminar, Magnetic Recording by the Engineer.

of the disc. The results were erratic and failure of the coating occurred only in the high humidity environments. Since both failure and increase in noise appeared to result from loss of plasticizer, some further tests were made to check this assumption. Acetate discs were exposed to the elevated temperatures in stagnant air of low and high humidities. The discs exposed at low humidity developed an oily film on their surface which could be removed either by washing or by exposing them to circulating air. After this film was removed from the disc surfaces, their playback behavior was the same as if they had been previously exposed in circulating air. The discs exposed at high humidity at first exhibited the same behavior as those exposed at low humidity and then failed by loss of adhesion, shrinking and cracking, embrittlement, and the development of minute pinholes in the surface. At the high humidities, so much plasticizer was exuded that it could not be removed as could the film on the surface of the low humidity discs.

The end result of loss of plasticizer closely duplicates the failures observed in many stored acetate discs as well as the increase in noise to signal ratio observed in aged acetate discs. In addition to the acceleration of plasticizer loss by heat and moisture, castor oil is readily consumed by fungi. In some cases there may be no surface evidence of this action (such effect was noted by the Army Quartermaster Corps who were studying the embrittlement of raincoats compounded with a fungi nutrient plasticizer) or there may be visible surface damage to the disc. A minor cause of increase in rate of loss of plasticizer may be occasioned by the wicking action of porous material in contact with the disc surface. The first precaution to be taken in the storage of acetate discs is to reduce

rate of loss of plasticizer to a minimum. It would be of benefit to deny access of oxygen to the discs, if this were feasible, or necessary in certain exceptional cases.

The next most important mechanism of chemical degradation of the acetate disc is degradation of the nitrocellulose itself. This was not judged to be of importance in the accelerated aging tests because, while Ultraviolet exposure accelerates the denitration reaction, there was no noticeable change in playback or coating failure characteristics between the exposed and unexposed discs. In long time storage, however, the degradation of the nitrocellulose is of importance as was demonstrated by the chemical analysis of a naturally aged disc. These reactions result in the reduction of molecular size with a consequent change in mechanical properties. The two reactions of importance are thermal and hydrolytic decomposition; ultimate degradation is evidence by extreme fragility. The only way to lower the rate of these reactions is to use lower temperatures and deny access of moisture to the disc.

Cellulose nitrate is also consumed by fungi and their excretions etch the disc surface. It is not consumed as readily as is the plasticizer, but the etching effect can be severe as was shown in a test in which fungi were grown on corrugated cardboard placed in contact with an acetate disc. The corrugation pattern was etched into the disc surface and the marring was much more pronounced than that from fungi growing less profusely on the disc surface itself.

Two items of especial interest were noted in the survey of acetate discs in storage. First, noticeable degradation of an acetate disc is not usually a slow, progressive development of embrittlement but usually a

sudden catastrophic failure of the coating. Second, premature failure of these discs seems to be common. It is believed that both of these phenomena result from accelerated loss of plasticizer which may be occasioned by fungal action or by a short time exposure to excessive temperatures in transit between factory and user.

To summarize our findings on the storage of acetate discs:

1. The surface should be protected from imprint or marring.
2. Rate of loss of plasticizer should be reduced to a minimum feasible value.
3. Thermal and hydrolytic decomposition of cellulose nitrate should be kept at a minimum.

The recommendations for accomplishing this are:

1. When a disc is acquired, it should be conditioned for approximately 24 hours in an atmosphere of 50 ± 10% R.H. at 70 ± 5°F.
2. It should then be sealed in a proper jacket. A proper jacket would:
   a. Be made of an inert, rigid, smooth, plastic-impervious to oxygen and moisture, and fungi resistant.
   b. Be constructed so that the disc can be inserted and removed without sliding contact between the surfaces.

   The commercial type disc jacket seems to require but slight modification in order to meet these specifications. Such modification could be:

   (1) Using a selected cardboard.
   (2) Coating the cardboard on all sides with a plastic (polyethylene, for example) material.

The commercial jacket is [illegible] 95%

Have they created a jacket for us?

(3) Changing the design of the open end so that it can be sealed with a pressure sensitive tape. and can be open without tearing jacket

(4) Making the jacket somewhat larger so that the hand can be placed under the label and the disc extracted without sliding contact between the disc surface and the jacket.

Incorporation of a fungicide in the jacket is not recommended because (1) no satisfactory fungicide is believed to be available and (2) use of a fungus resistant jacket coating and low humidity inside the jacket are adequate protection against fungal attack.

13. The disc should be stored in the vertical attitude so that no gravity loads are exerted on the surface.

14. The stack area should be maintained at 50 ± 10% R.H. and 70 ± 5°F.

15. The disc should be cleaned before and after playback.

with what? How?

Under these storage conditions (and if its longevity has not been seriously decreased before acquisition) a well made acetate disc should have an estimated storage life of about 25 years. During this time, the noise to signal ratio should increase. According to the U. S. Navy Underwater Sound Laboratory data on actual stored records,(1) an average increase in noise level of about 6 db can be expected in half that time and the eventual increase might be in the order of 20 db.

SHELLAC DISCS

Many of the early shellac discs were laminates, but the majority of stored shellacs are of the composition type. The best such formulation consisted of shellac, copal resin, carbon black, and crushed limestone. Unfortunately, it is almost impossible to differentiate by inspection between a good shellac disc and one which used one or more of the innumerable substitute binders or fillers. Shellac of uniform properties was seldom obtainable and it was often extended as much as 200% or replaced entirely by other materials. Cellulosic material and clay were probably as commonly used as filler as was crushed limestone. As a result, few definitive statements can be made about shellac discs and but one formulation was studied in this program in order to determine only the aging properties of a true shellac disc.

Raw shellac is a solid solution of a number of organic compounds. As it ages, the compounds react together to form an intricately cross linked resin and water. A semi-quantitative method of judging the extent of this reaction is to measure its solubility in alcohol. The raw shellac is almost completely soluble while completely "cured" shellac is insoluble. This condensation reaction is accelerated by heat and moisture up to a certain temperature, after which it is reversible.

The shellac in a freshly pressed disc is incompletely "cured", that is, the reactions between the organic compounds of the raw shellac have not attained equilibrium in the processing and molding operations. The slow continuation of these internal reactions seems to be the major aging mechanism of shellac discs. The manifestation of such aging is loss of

resilience, increase in hardness, embrittlement, and shrinking. The only way of inhibiting these reactions is to lower the environmental temperature and water content.

The good feature of this internal reaction is that its rate decreases with time (as opposed to the self-catalyzing reaction of vinyl, for example) and that degradation should be progressive and not catastrophic in nature. The plastic properties of shellac and its adhesive properties practically preclude surface cracking. The inherent hardness and resilience of shellac provide a considerable reserve of strength against embrittlement, especially when modern playback equipment is used. As a result, well stored shellacs should have a long (if unpredictable) storage life during which the discs gradually become more and more brittle. There is, unfortunately, no index which can be established for judging degree of embrittlement--because of the variation in original composition of the materials--and no such simple behavior can be expected from many of the discs of inferior formulation.

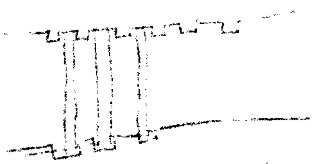
The warping behavior of a shellac disc changes during its aging. Unlike the vinyl discs, the freshly pressed shellac has no significant initial internal stresses or strains. This is because the raw shellac molecules are so small that they behave as does a viscous liquid. A freshly pressed shellac disc, warped by gravity loads, may be completely restored to its proper shape by merely increasing its temperature while it is in the horizontal attitude. As the shellac ages, however, the cross linking not only increases its resistance to warping from gravity loads but creates internal stresses which tend to deform the disc and also "freeze in" any strains that are present.

Laboratory comparisons between horizontal and vertical storage attitudes indicate that the likelihood of surface imprint in horizontal storage is so great that vertical storage should be used despite the potential danger of warp from gravity loads in the off-vertical attitude. This means that great care must be taken in the design and use of shelves for these discs.

Shellac discs vary in fungi resistance but because it is difficult to identify the ingredients of such a disc and because so many discs include excellent fungi nutrient waxes and cellulosic products, it is best to assume that a shellac disc is fungi susceptible. The best way of preventing the growth of fungi is to keep the humidity below 60% R.H.

Shellac, except for its internal reaction of "curing", has very good aging qualities. This is indicated not only by the number of shellac discs over fifty years old which are still in good condition, but by the shellac objects in museums and archeological collections. It is the adulterants and substitutes which require protection against oxidation and the other external agents of degradation with the exception of moisture. Moisture is most deleterious to shellac and it is the most temperature sensitive of the binders in a freshly pressed disc--as the disc ages both of these factors assume less importance in storage criteria. Despite the greater stability of good shellac, the same recommendations for storage of shellac discs are made as for acetate discs with the additional recommendation that shelving be so designed that gravity loads which would tend to warp the discs be minimized. While a flexible envelope would be satisfactory for the acetate disc, a rigid jacket is demanded by the shellac disc. Since the cellulosic jacket has been found

to breed fungi as well as to cause warp because of its own moisture induced warping, a cellulosic jacket protected from the environment by an inert plastic coating is recommended.



We should proceed to accept since relatively [illegible] [illegible] [illegible] [illegible] are [illegible]. Why not use a ~~[illegible]~~ 1 cent [illegible] [illegible] [illegible] instead of 1 sq. yard?

What caused the [illegible], dropping out of antenna and [illegible] [illegible] [illegible] [illegible] 50 years [illegible] [illegible] the [illegible]?

[illegible]

[illegible]

[illegible]

[illegible]

THE VINYL DISC

There are more [illegible] formulating vinyl discs [illegible] in the [illegible] in the [illegible]

The vinyl disc poses a unique problem in this investigation. The acetate disc has been in use nearly as long as its potential life span. The obsolete shellac disc, although having a relatively long life, is unpredictable because of its variety in formulation. On the other hand, the composition of modern, well-made vinyl discs is standardized, and there is no "well-made" and "well-cared-for" vinyl disc old enough to have failed from chemical degradation. Accordingly, an estimate of the length of time a vinyl disc can be stored, before significant chemical degradation occurs, was needed to determine the parameters of storage degradation which are of consequence to the librarian. To formulate an estimate, a literature search was conducted and assistance was obtained from research chemists in the vinyl plastic industry.

The most significant mechanism of chemical degradation of polyvinyl chloride is the dehydrochlorination of the PVC which ultimately results in further polymerization and cross linking. The manifestation of this series of reactions is surface embrittlement and undesirable dimensional changes. The dehydrochlorination rate is a function of available oxygen, temperature, and free hydrogen chloride (which catalyzes the reaction). Fortunately, there is a measure of this dehydrochlorination. The vinyl disc formulation contains a stabilizer which reacts with the liberated hydrogen chloride. As long as the stabilizer is 100% effective, the rate of dehydrochlorination remains a constant function of the temperature and the PVC does not deteriorate significantly. When the stabilizer becomes ineffective, however, the reaction becomes autocatalytic.

Maybe we should [illegible] the jacket or [illegible] with the stabilizer [illegible] inspection.

and the material degrades rapidly. For all practical purposes, the life of the vinyl disc can be considered to be equal to the effective life of the stabilizer.

A perfectly valid estimate for all vinyl discs cannot, of course, be made because of some variety in formulations, as well as the lack of knowledge of the thermal history of the material (especially the thermal history during milling and pressing). The estimate made here is, however, considered to be worthwhile because it gives not only an idea of potential disc life, but it also shows the effect of environmental temperature on such potential life.

A survey of formulations indicates that many high quality disc formulations contain 1.5% by weight of dibasic lead stearate. This was chosen as the basis for the following estimate:

$$0.015 \text{ grams/gram DS-207} \times 1000 \div 1015.36 = 0.015 \text{ millimoles DS-207}$$

will react with

$$4 \times 0.78 \times 0.015 = 0.05 \text{ millimoles HCl/gram}$$ cumulative?

before free HCl begins to escape.

Assuming processing consists of a thermal exposure history equivalent to 50 minutes at 340°F, this would result in between 0.01 and 0.02 millimoles of HCl being liberated by the PVC or about 0.03 millimoles HCl equivalent remaining effective stabilizer. can it be exposed?

Using the Arrhenius equation, which seems to be perfectly applicable to this reaction, a reasonable and conservative approximate formula for the life of this amount of stabilizer seems to be:

$$t = \log^{-1}\left[-12.45 + \left(\frac{10,000}{460 + T}\right)\right]$$

where t is time in hours and T is temperature in degrees Fahrenheit, (based on Druesedow and Gibbs elevated temperature data,[1] and private communications with manufacturers of PVC resin). Representative solutions of this equation are:

70°F	2.63×10^6	hours or	300 years
80°F	1.18×10^6	"	135 "
90°F	5.37×10^5	"	61 "
100°F	2.57×10^5	"	29 "

One major recording company uses an inferior material in LP records to this--by extending the copolymer with a cellulosic by-product resin--and flash is sometimes reused. Otherwise, this seems to be a good estimate of potential life of the material.

While no example of failure of the material was found, a large number of examples of failure by warping were found, and this was extensively investigated in this program. The more serious warping did not appear to result from creep from gravity loads because of the deformed shapes of the discs. The types of warp that were observed were duplicated in the laboratory by thermal cycling and by the relaxation of "internal stresses".* An estimate, based on laboratory studies, of gravity load induced warp was also made and indicated that this was not a significant parameter under good storage conditions.

(1) Druesedow and Gibbs, "Effect of Heat and Light on Polyvinyl Chloride", Modern Plastics, Vol. 30, No. 10, pp. 123ff. (June 1953).

* "Internal stresses", as discussed here, are not the stresses normally described as residual or "locked-in" stresses. Instead, they refer to internal stresses generated by the molecular configurational strain relaxations of the molecules.

Warp from thermal cycling can be, of course, prevented. Warp from the "internal stresses" can only be inhibited under library conditions, and the only means of inhibiting this warp is to reduce the environmental temperature to the lowest value compatible with library operation.

Vinyl is the most fungi resistant material used in recording discs. Fungi cannot be ignored in storage, however, because of the possibility of fungi growing on other nutrient media and etching the vinyl disc with their secretions. This was found in laboratory tests to produce serious surface marring. This is best prevented by keeping records free of grease and oils, not using fungi nutrient envelopes and separators, and by keeping the humidity below 60% R.H. at room temperature.

Vinyl discs, unlike acetate and shellac discs are unaffected by moisture--either chemically or dimensionally. Humidity control is not essential, except for fungal growth inhibition.

The same storage techniques and environments are recommended for vinyl discs as for shellac discs.

RESUME OF DISC STUDY TO DATE

		Acetate	Shellac	Vinyl
1.	Type of Construction	Laminate	Composition	Plastic
2.	Basic Formulation	Nitrocellulose plasticized with castor oil.	*Shellac, copal resin, mineral filler.	Copolymer of vinyl chloride - acetate, unplasticized.
3.	Fungi Rating	Very susceptible.	Often very susceptible; depends on formulation.	Resistant to growth; not resistant to etching.
4.	Reaction to Excess Moisture	Chemical degradation; some dimensional changes.	Chemical degradation; serious dimensional changes.	Unaffected.
5.	Heat Resistance	Poor; thermal cycling probably accelerates loss of coating adhesion.	Poor; thermal cycling is not detrimental to a good genuine shellac.	Poor; thermal cycling is very detrimental dimensionally.
6.	Light Resistance	Very poor.	Good to poor.	Poor.
7.	Abrasion Resistance	Poor.	Poor.	Poor.
8.	Probable Modes of Failure	Catastrophic failure of coating; embrittlement.	Embrittlement; warping.	Warping; embrittlement.
9.	Probable Causes of Failure	Loss of plasticizer or denitration of polymer.	Loss of extender or condensation of shellac.	Internal stresses; loss of extender; cross-linking.
10.	Response to Aging Prior to Failure	Increase of noise with no detectable change in frequency response or distortion.	Increase of tensile modulus of elasticity.	Increase of undesirable deformations.

* This is a best formulation, not necessarily a most common one. There is not a typical shellac formulation.

Recommended environment for all discs:

I. Stack Environment

A. Constant temperature of 70 ± 5°F.

B. Constant humidity of 50 ± 10% R.H.

C. Dust free.

II. Shelf Design

A. Vertical storage attitude.

B. Frequent dividers to prevent off-vertical attitude.

C. All compartments in use should be kept full, either with discs or with discs and filler units.

D. No loads should be exerted on the discs.

III. Disc Jacket Design

A. The envelope and jacket should be of one piece construction, so designed that the disc may be removed and inserted without sliding contact between envelope and disc.

B. In order to derive the benefit of the stiffness of cardboard and the inertness and smoothness of plastic, a cardboard coated with an inert, rigid, smooth plastic--impervious to oxygen and moisture and fungi resistant--is recommended.

C. Open edges of the envelope-jacket should be sealable. (A suitable jacket design was described in the discussion of acetate discs; other materials are still being studied.)

IV. Storage Technique

Prior to placing discs in envelopes, they should be:

A. Cleaned with a nylon pad and, possibly, a detergent (such as Electrostat Kit). — Will they recommending this for cleaning all discs?

B. Conditioned in a dust free atmosphere for 24 hours at 50 ± 10% R.H. and 70 ± 5°F.

Although the fundamental reasons for these recommendations vary with the variations in disc type, this environment is recommended for all types of discs.

It was hoped that a fungicide suitable for incorporation in the jacket material would be found. Such a fungicide would have to be compatible with all of the ingredients used in disc formulations and would have to have the property of slow release from the jacket material over a long period of time. No material was found which possesses all of these properties. Instead, an equally good anti-fungus measure is proposed. That is, the use of a fungus resistant coating and of low humidity inside the jacket. Probably the greatest objection to the fungicides studied is the catalytic action of fungicidal chemicals on the degradation rate of nitrocellulose, as well as many of the unstable commonly used extender materials.

The feasibility of using coatings--such as silicone or thin metallic films--was considered. Such a coating could act as a barrier to external agents of degradation and has been successfully developed for motion picture film. It is felt, however, that this will be successfully accomplished by an improved disc jacket and coatings have the following objections:

Wouldn't coating prevent this?

1. For acetate discs, aging forces out plasticizer which would damage coating smoothness and coherence.
2. For shellac discs, aging forces out water which would damage coating smoothness and coherence.
3. For vinyl discs, the aging mechanism to be resisted is

warping which would require too thick a coating for microgroove discs.

4. The surface properties of discs are very important in playback. This is why softeners, waxes, and lubricants are incorporated into many formulations. A coating adequate to serve as a barrier would change these surface properties.

5. Playback, because of the varying forces exerted on the groove walls, would cause uneven wear of the coating which would be undesirable

MAGNETIC TAPE

The most common causes of fidelity loss in tape playback are:

1. Physical distortion of the tape.

2. Separation of coating from backing.

3. Print through.

4. Tape demagnetization.

Figure 1 is a set of curves which were made using $1\frac{1}{2}$ mil general coating tape and a professional type recorder. While such curves are a function of the particular tape and recorder used in a test, the general characteristics of all such curves are similar. Curve Number One was made using record and playback heads and an ordinary amplifier; it shows the actual tape output. Curve Number Two is a similar curve, using the recorder amplifier which has equalization. Curve Number Three is a playback of the tape of Curve Number One through an ordinary amplifier with a 1 mil separation between head and tape; Curve Number Four is the same with a 2 mil separation between head and tape. Curve Number Five is a playback of the tape of Curve Number Two through the recorder amplifier with a 1 mil separation between head and tape. Curve Number Six is a print through signal of tape number two developed by high temperature exposure and played back through the recorder amplifier.

A comparison between Curves Number Two and Five demonstrates the signal amplitude variations which arise from but a 1 mil fluctuation in distance between tape and playback head, and, especially, the loss of high frequency response. A comparison between Curves Three and Four indicates the additional loss which might be expected from a 2 mil separation between

tape and head.

In a professional type recorder, contact between tape and head is maintained by the components of tape tension in the head direction. Contact is lost by such things as (1) longitudinal waves in the tape induced by variations in this tension caused by differences in tape adhesion at supply reel or frictional characteristics of the tape as it slides across the heads, (2) permanent curvature of the tape caused by creep of the tape while on the supply reel, (3) cupping of the tape caused by differential dimensional changes between coating and backing, (4) fluting of the edges induced by storage of poorly wound tape, (5) wrinkling or warping of the tape caused by creep of the tape while stored. An additional fidelity loss is occasioned by frequency shifts due to stretching or shrinking of the tape.

Physical distortion of the tape results from the nature of the material itself, from the way it is stored, and the environment it is stored in. The material, itself, has molecular configurational strains from the manufacturing process, is visco-elastic, and is a laminate. It is stored on a reel under tension, often poorly wound, and the reel has a slotted hub and is often plastic. The environment can provide temperature and humidity variations which can induce high stresses in the tape.

The storage reel is the first source of tape distortion. While the metal NARTB 10" reel seems to be quite good, libraries often use the smaller plastic reels. (The smaller radius of curvature at the hub increases both the amount of tape curvature resulting from creep and the effect of the hub slot which causes a localized distortion of the tape) An additional

What is the correct tension?

fault of plastic reels is flange warping which often is serious enough to damage edges of the tape both in storage and playback. It is recommended that tapes to be stored for over ten years be stored only on the 10" NARTB metal reel. It would also be preferable to use an unslotted hub even for this reel. Warped reels should be discarded.

The next source of tape distortion is in winding. A commonly used winding tension is seven ounces at the hub of ten and seven inch reels and five ounces at the hub of five inch reels. This is a fairly high initial stress for plastic films and any unevenness in winding, especially in the presence of additional thermal or humidity induced stress, results in edge fluting, wrinkling or warping of the tape. Tape tension must be a compromise between a loose wind, which permits "spiderwebbing" and cupping, and a tight wind, which causes excessive dimensional changes. Excessive tension increases physical distortion, tape sticking, and print through. At present, seven ounces seems excessive for the seven inch reel and perhaps somewhat high for the ten inch reel. Some tape manufacturers use a winding curve which is a compromise between constant torque and constant tension; the tensions used by manufacturers seem to be excessive for tape storage purposes. Tapes should be rewound on a special device before storage instead of being taken from the tape deck and stored.

absolutely!

The final sources of tape distortion are fluctuations in temperature and humidity, unequal dimensional changes between coating and backing, and relaxation of "internal stresses". In order to avoid these effects, storage at constant temperature and humidity is required. Recommended procedure is to condition a tape for 24 hours in an environment

of 70 ± 5°F and 50 ± 10% R.H., and then to seal it in a can or a plastic bag impervious to moisture. The container should then be kept is an environment of 70 ± 5°F and 50 ± 10% R.H.

Some coatings seem to be fungi nutrient, some are plasticized, some become tacky in the presence of excess moisture or high temperature, and all of them seem to be somewhat pressure sensitive. Despite our efforts to obtain coating formulations, to date we have been unsuccessful in doing so because they are closely guarded trade secrets. We know nothing of modern coatings except that some manufacturers say that their coatings are superior to those of other manufacturers. Permafilm is experimenting with a protective coating for the tape coating, one manufacturer makes a laminate instrumentation tape with the coating sandwiched between backing material; but, at present, all we can recommend is fungi inhibition and the use of low temperature, low humidity, and low stress, together with the use of the coating which has the best rating in the accelerated aging tests.

The next two figures show some of the characteristics of print through. Most important, perhaps, is that it follows reaction laws and is an asymptotic function. Its maximum value is a function of the strength of the master signal, distance from master signal, temperature, stress, and external magnetic fields. Print through can be kept below noise level by control of these parameters. Frequent rewinding does seem to be a good idea, as far print through goes, for extremely long time storage because while it does not reduce the print through appreciably it does change its identity from an audible signal to noise. Selective erasure is not recommended for library use because of loss of high frequency signal.

Figure 4 shows the first time erasure characteristics of a printed signal and a biased signal which permits a decrease of print through to master signal ratio. Further erasure is a function of the logarithm of the number of erasures, with respect to the master signal, with the first time value of erasure with respect to "new" print through. Unfortunately, each frequency requires a different erase current for proper selective erasure so that high frequencies are attenuated too much with the current required for erasure of middle frequency print through. For tapes which do not cover a wide range of frequencies, selective erasure is a good emergency treatment prior to re-recording for preservation of the transcriptions.

with magnet bugaboo? proper direction

Tape demagnetization under excellent storage conditions is insignificant; the maximum measurable amount being in the order of 1 to 2 db at the higher frequencies for very long storage times. At elevated temperatures (above 90°F) or in the presence of external magnetic fields greater than 15 gauss it begins to be measureable. Demagnetization obeys the same diffusion laws as does print through.

water & damp?

To summarize these remarks on tape:

1. Small hub or plastic reels should not be used. A 10" metal reel with an unslotted hub is recommended.

2. Tapes should be rewound on a special winding device before storing. what tension?

3. Tapes should be conditioned to 70 ± 5°F and 50 ± 10% R.H. for 24 hours and then sealed in a container. what container?

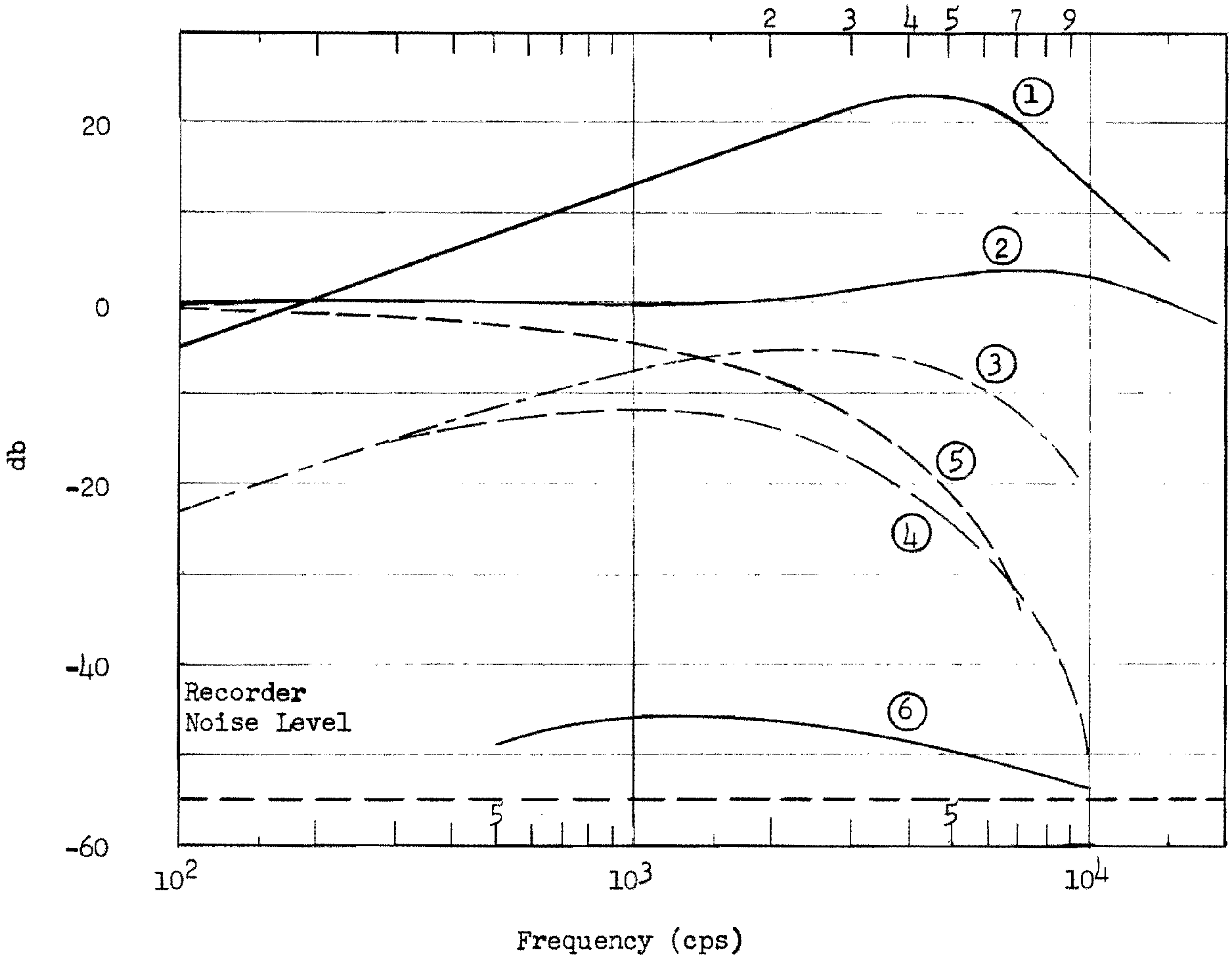
4. This container should be kept in a room at 70 ± 5°F and 50 ± 10% R.H. stored on edge on shelves made of wood or non-magnetized metal. Precious tapes could be conditioned to 50 ± 5°F and stored at this

[illegible] they are reconditioned to 70°F before playback; this would [illegible] through considerably.

[illegible] stray external magnetic fields in the storage area should [illegible]. These fields should never exceed 10 gauss.

[illegible] tapes of only ten years ago had a potential storage life of only [illegible] years because of the rapid rate of chemical degradation. The [illegible] improvements in plastic materials used in tape manufacture have ex- [illegible] this potential life to ten times that value, or perhaps more. One [illegible] predict actual life unless he knows more of the coating formulation [illegible] do at present. (nothing!) This increase in longevity changes the probable [illegible] of loss of fidelity from degradation of the material to physical [illegible] and magnetic changes. Fidelity loss from these sources can [illegible] controlled with proper storage technique and environment. But what are the techniques?

We have 1947-48-49-50 tapes even some 1943 German Tapes and all can still be played and with good fidelity.



1 Actual Tape Output - Constant Power Input

2 Recorder Output - Equalization

3 Actual Tape Output - Tape 1 mil from Head

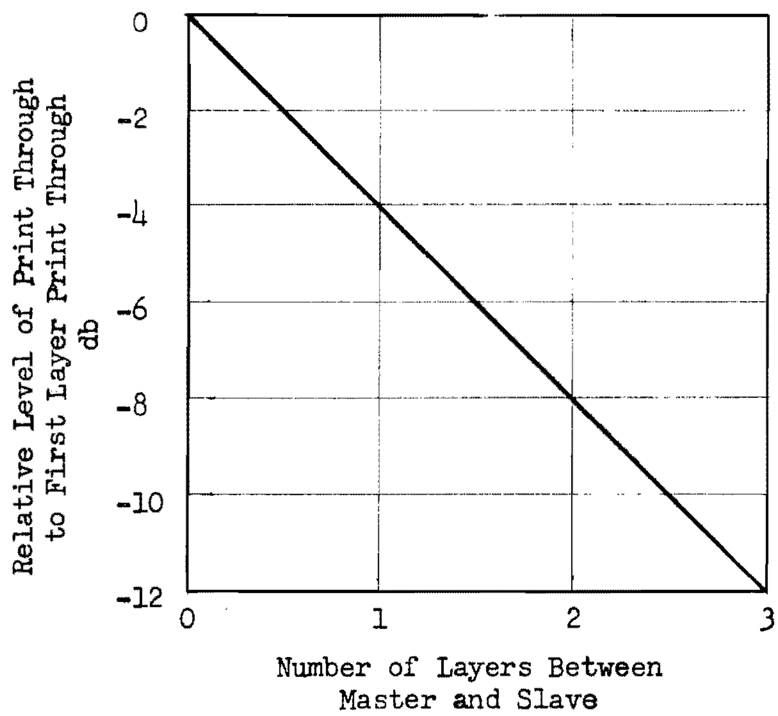
4 Actual Tape Output - Tape 2 mil from Head

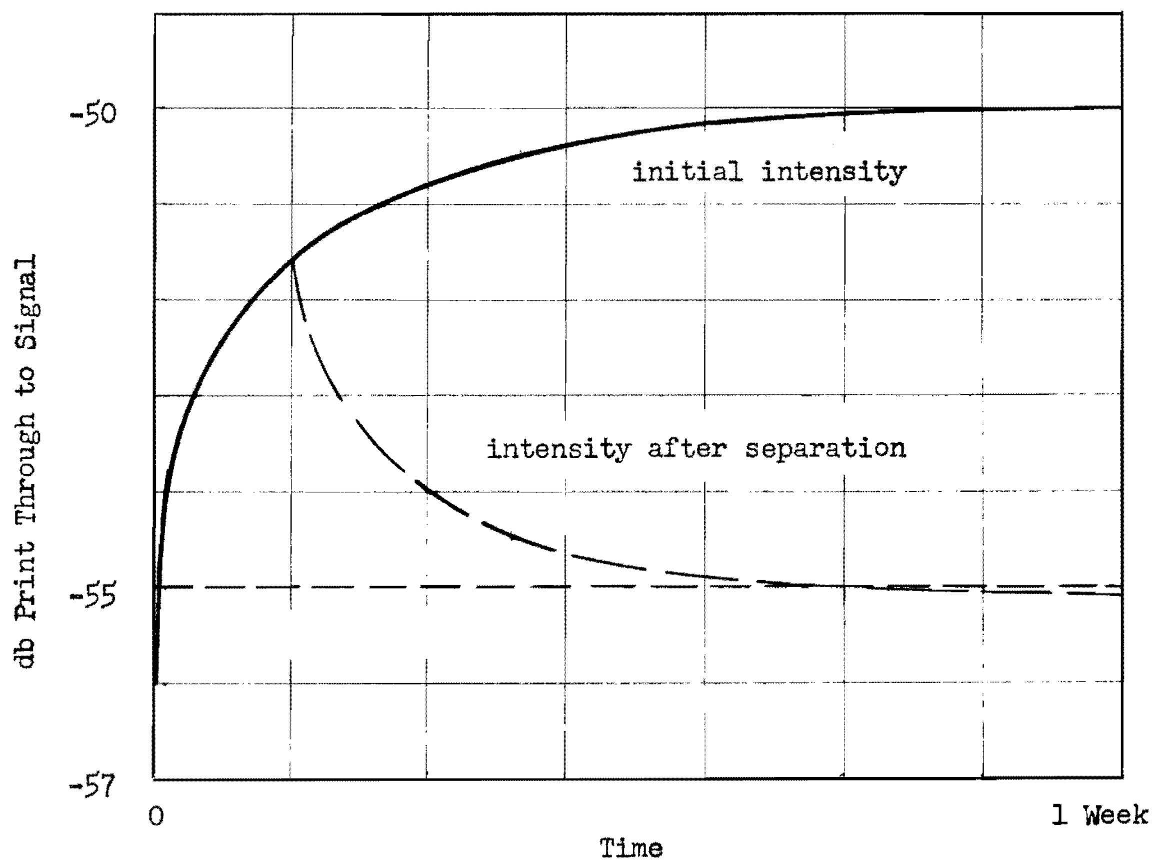
5 Recorder Output - Tape 1 mil from Head

6 Print Through (Estimated 20 year level)

Characteristic Data for a General Coated,
1.5 Mil Tape Showing the Interrelationship of
Various Parameters (Actual Values Depend on Tape and Recorder)

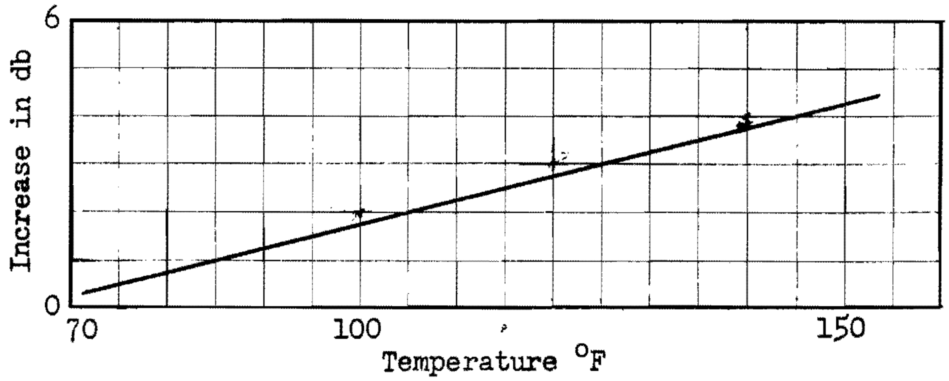
FIGURE 1



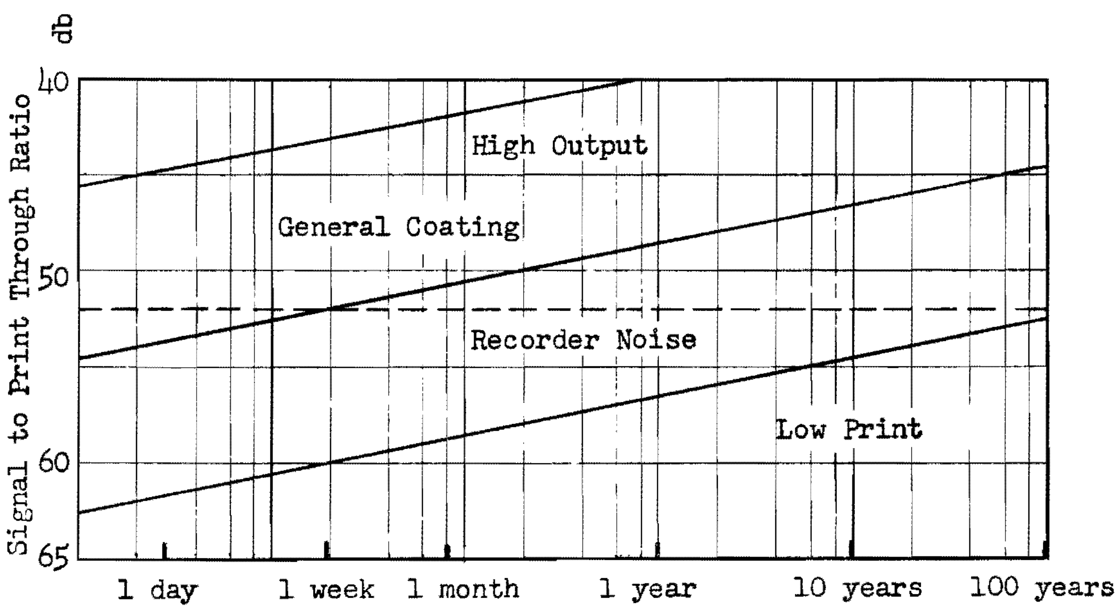


Typical Print Through Curve
Ambient Temperature; 1000 cps; 15 ips
$1\frac{1}{2}$ mil General Coating Tape

FIGURE 2



Print Through as a Function of Temperature
7.5 ips; 400 cps; 3% Total Distortion
(Audio Devices)



Time of Contact
(Audio Devices)

FIGURE 3

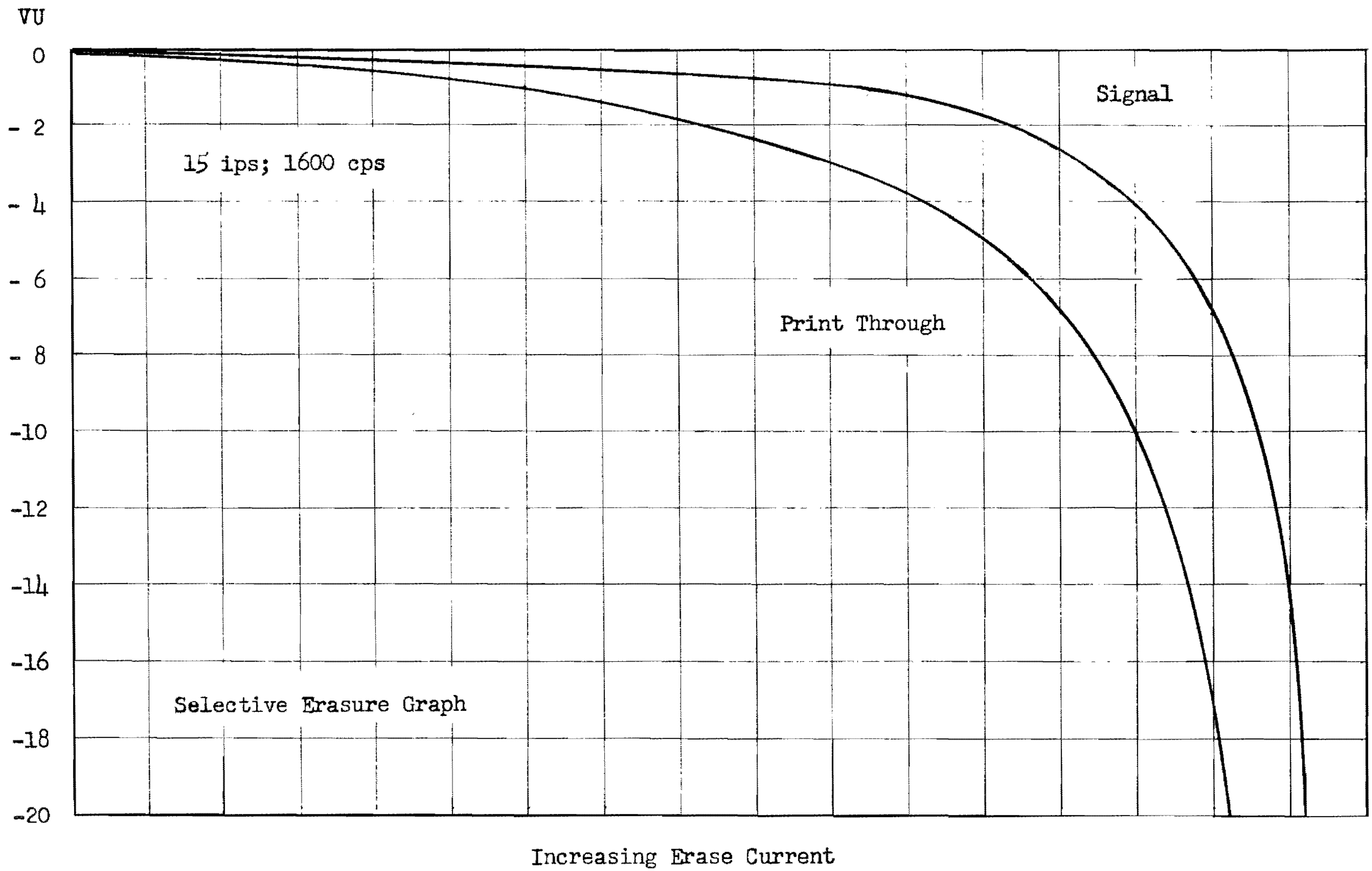

VU
0
- 2
- 4
- 6
- 8
-10
-12
-14
-16
-18
-20
Signal
15 ips; 1600 cps
Print Through
Selective Erasure Graph
Increasing Erase Current

FIGURE 4